

DEGRADATION OF ELECTRO-OPTIC COMPONENTS ABOARD LDEF

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SUMMARY

Remeasurement of the properties of a set of electro-optic components exposed to the low-earth environment aboard LDEF indicates that most components survived quite well. Typical components showed some effects related to the space environment unless well protected. The effects were often small but significant. Results for semiconductor infrared detectors, lasers, and LED's, as well as filters, mirrors, and black paints are described. Semiconductor detectors and emitters were scarred but reproduced their original characteristics. Spectral characteristics of multi-layer dielectric filters and mirrors were found to be altered and degraded. Increased absorption in black paints indicates an increase in absorption sites, giving rise to enhanced performance as coatings for baffles and sunscreens.

INTRODUCTION

The LDEF Active Optical Systems Component Experiment consisted of over 100 electro-optic components both mounted on an LDEF tray and stored as controls. The tray location was near the space end and toward the rear of the satellite. A preliminary report was presented at the 1991 First LDEF Post-Retrieval Symposium¹. During the past year we have continued measurement and analysis of component properties. Design of the mounting hardware, along with the associated thermal and structural considerations, was discussed in the previous report¹. Here, we present additional data and discuss our conclusions regarding the observed property changes for the components. Component measurements are still in process, and modifications to our conclusions are possible.

The objective of these measurements is to establish guidelines for the selection and use of such components in space-based electro-optic systems.

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INFRARED DETECTORS

No changes were found in the properties of six large-area silicon photovoltaic detectors (800 mm²) after retrieval. Typical results for measurements of junction capacitance, junction leakage current, and noise spectral density are presented in Figures 1-3 respectively. Capacitance, Fig. 1, was unchanged for all devices. Junction current in Fig. 2 represents current for a diode struck by a micrometeorite leaving a visible scar. A photograph of the impact site was presented previously.¹ Fig. 3 shows that the current noise for the device was well below specifications after recovery. Responsivity and noise show no change for any of our silicon detectors. These devices were mounted so as to expose the active surface to the space environment in order to maximize possible degradation effects.

Remeasurement of properties of other infrared detectors is in process. The task is made more difficult because of the extended time period between original and present measurements. In some cases it has been difficult to reproduce the original measurement conditions because of changes in equipment. At this time, the only infrared detectors in this set of components which indicate apparent degradation are part of a group of pyroelectric detectors.

Properties of a group of 31 pyroelectric infrared detectors (including 10 stored as controls) were reported by Dr. James Robertson, NASA Langley Research Center.²

Detectors fabricated from several pyroelectric materials were included in the group. Triglycine sulphate material did not perform well. All detectors but one made from this material failed including the controls. Triglycine sulfate is an exception to the overall good performance of all detector materials measured to date.

LASERS AND RELATED COMPONENTS

While the gas lasers in our component set did not survive the extended period in orbit, GaAlAs semiconductor lasers were not changed by their exposure to the space environment. Remeasurement of Nd:YAG laser rods awaited refurbishment of the original laser cavity which had deteriorated. With new pump lamps and a replated cavity, the rods performed even better than the original measurements. The results are presented in Table 1.

Three Nd:YAG rods were included in the components set. Two were mounted in the tray beneath an aluminum cover (simulating the minimum protection expected in a typical installation) while the third was stored as a control. Characterization of the rods assumes a linear relation between input pump energy and output laser-pulse energy with an intercept on

the pump-energy axis. The measurements then provided the slope and intercept characterizing this relationship between input and output energies for the rods in specific positions in the three-rod laser cavity. The required cavity improvements made the cavity more efficient, and the remeasured coefficients indicated better performance than the original measurements.

Table 1. Nd:YAG Rod Properties

	Control	Rod #1	Rod #2
Prelaunch			
Slope Efficiency, (mJ/J)	24.6	22.6	23.6
Intercept, (J)	7.6	7.1	7.0
Postrecovery			
Slope Efficiency, (mJ/J)	36.2	35.0	35.2
Intercept, (J)	3.8	3.1	3.1

The space-exposed rods and the control had the same relative change in measured characteristics. The relationship among the rods remains the same as in the original measurements. Even the $1/4\lambda$ coating on the ends of each rod survived in good condition. We conclude that the changes in parameters were due only to the changes in the cavity, and that space exposure did not change the rod properties.

Other laser related components in this group were an ADP (ammonium-dihydrogen phosphate) electro-optic modulator and a laser flash lamp. No changes were found in the properties of these components post-recovery. The spectral output of the flashlamp reproduced the original measurements. For the modulator, the transmission, roll-off frequency, and half-wave voltage were unchanged. Laser-cavity mirrors are discussed in a separate section.

Light emitting diodes (Monsanto GaAsP LED's) also remained unchanged whether stored in our laboratory or mounted on the LDEF tray. Figure 4 shows light output for a space-exposed diode and a control diode. The original characteristics for both diodes are well reproduced. The stored diode has slightly greater quantum efficiency, while the plastic dome of the space-exposed diode carries the indentations of small micrometeorites.

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OPTICAL FILTERS

Our set of nine optical filters included three different filter types. These types were narrow-band filters, wide-band filters, and neutral-density filters. One example of each filter type was placed under an aluminum cover to protect it from direct space exposure. The remaining filters were directly exposed to the space environment.

The narrow-band filters, composed of quarter-wave thick stacks of dielectric materials, showed evidence of reduced transmittance, shift of the center wavelength, and bandpass broadening, although the covered filter showed only a reduction in transmittance with no shift of center wavelength or bandpass. Wide-band filters (composed of 11 pairs of ZnS/ThF₄) also had reduced transmittance and showed evidence of deterioration of the interference coatings as a result of the space exposure. The covered filter experienced a similar but smaller amount of degradation than the exposed filter.

Neutral density filters did not use quarter-wave dielectric stacks. These filters are composed of a single layer of Inconel metal which provides approximately uniform attenuation across the visible spectrum. The sample exposed to the space environment had slightly increased transmission. The covered sample was unchanged.

Explanations of the unexpected results must consider the differences between the exposed and covered filters, the modest amount of ionizing radiation (less than 300 krad), the negligible oxygen flux (less than one oxygen atom per 100 surface atoms), and the absence of any visible deterioration after retrieval.

Consideration of the results for the filters, mirrors (following section), and detector windows leads to the following speculations regarding the physical phenomena that are believed to be the major causes of the observed changes in this set of optical filters. Details concerning the degradation of the filters can be found in an earlier paper.³

Narrow-Band Filters (Three Effects)

Drop in Transmittance

Degradation and aging of the cement or varnish used to attach the cover glass by UV and other radiation increases opacity and reduces throughput.

Band-Pass Shift

Years of temperature cycles (>32000) increase packing density and reduce average filter-layer thickness which causes a band-pass shift toward the blue (depends upon materials).

Band-Width Increase

Temperature driven interdiffusion between the interference layers reduces interlayer reflectivity and increases filter bandwidth (depends upon materials).

Wide-Band Filters (Two Effects)

Disruption of Design Tolerance

As with the narrow-band filters, interdiffusion disrupts the design balance and reduces the effectiveness of the design causing degraded cutoff slope and deeper and wider ripples in the transmission spectra.

Drop In Transmittance

The reduced interlayer reflectivity not only degraded the design, but also caused reduced transmittance. Thus, even the hot mirror under cover suffered reduced transmittance. In addition, the exposed filter may have experienced erosion as contamination at the exposed surface caused additional transmittance loss.

Neutral-Density Filters (One Effect)

Increase In Transmittance

The slight increase in transmittance for the exposed filter is likely due to erosion plus a small amount of pre-launch and pre-recovery oxidation. The covered filter may have a slight (less than 0.1%) increase in transmittance due also to oxidation.

LASER MIRRORS

A set of 25 laser mirrors were provided by AFWL (now Phillips Lab.) for the component set. The mirrors were quarter-wave dielectric stacks over copper- or silver-plated quartz or metal substrates. All mirrors were optimized for high reflectivity at 2.8 μm or 3.8 μm . Post-retrieval examination of the mirrors revealed no evidence of peeling, flaking, or loss of adhesion. Scratches and lap marks were evident along with residual particles of lapping compound at the end of some of the tracks. No unusual features such as dendrite formation or impact craters were noted during surface examination. A more extensive search should reveal some craters since they were seen on other trailing-edge components.

During a general refurbishment and updating of the component set in 1983, six laser mirrors were found to be developing pin holes, or flaking and peeling. These mirrors were replaced. Many of the deteriorating mirrors were constructed using ZnS/ThF₄ layer pairs.

Most mirrors show a five to twenty-five percent drop in reflectance assuming that the original reflectance was close to 100 percent. As with the optical filters, small changes in properties of these multi-layer films can result in significant changes in reflectivity and loss of performance. The source of the changes may be interdiffusion at the interface between the layers, erosion or contamination at the surface, and damage in the layers from the particulate radiation falling on the surface.

Figure 5 shows the normal spectral reflectance of the best mirror in the set plotted against reciprocal wavelength (wavenumbers). Original records indicate that this mirror was

composed of (Ge/ZnS) layers on a copper-plated metal substrate, and was designed for high reflectance at $3.8 \mu\text{m}$ (3571 cm^{-1}). The edges of these mirrors were covered by the attachment hardware and always had a different reflectance characteristic. As judged by the results of this set of filters, the conventional ZnS/ThF₄ or ZnSe/ThF₄ dielectric pairs are not as suitable as some of the other material combinations included in this group of mirrors. The use of Si/SiO pairs gave better stability, and Ge/ZnS was the best material combination.

BLACK PAINTS

Figure 6 shows the normal reflectivity at extreme infrared wavelengths for Chemglaze Z306. These results are typical for all six black paint samples in our component set. After recovery, all black paint samples showed decreased reflectance in this spectral region. The solid lines are calculated using the expressions developed by Smith⁴ and using the parameters found by Smith for Z306 for the prelaunch case. Postrecovery calculations used the same parameters except that the imaginary part of the refractive index was increased from 0.06 to 0.22. The implication is that exposure increased the number of absorption sites and made the paints blacker. Energy loss caused by increased scattering was negligible. The fit could be improved by allowing the real and imaginary indices to vary with wavelength, but we have no firm physical basis for such modifications at this time. Details of the reflectance spectra analysis can be found in an earlier paper.⁵

CONCLUSIONS

The findings of other investigators as well as our own suggest that material characteristics play a major role in determining degradation of optical components in space. Dielectric stack coatings are sensitive indicators of change in dimensions or physical parameters. Rigid materials such as ceramics, glasses, and covalently-bonded semiconductors such as silicon, withstand space exposure well.

Weakly-bonded materials such as some of the halides and plastics, as well as multi-layer dielectric structures in mirrors and filters are at risk. Protection for devices using such materials should be provided if possible.

Radiation levels are modest for most optical devices, although not all. Radiation protection can easily be provided in most cases. Contamination of optical surfaces can be significant as shown by the results for the LDEF. Again, some type of surface protection is

necessary in order to permit the contaminants to condense elsewhere and become fixed in place before exposing sensitive optical surfaces to the environment.

REFERENCES

1. Blue, M.D.: "LDEF Active Optical Components Experiment." 69 Months in Space--First LDEF Post-Retrieval Symposium, NASA CP-3134, Part 3 January 1992.
2. Robertson, J.B.: "Pyroelectric Detectors On LDEF." 69 Months in Space--First LDEF Post-Retrieval Symposium, NASA CP-3134, Part 3 January 1992.
3. Blue, M.D. and Roberts, D.W.: "Effects of Space Exposure on Optical Filters." Applied Opt., vol. 31, no. 25, pp. 5299-5304, September 1992.
4. Smith, S.M.: "Specular Reflectance of Optical-Black Coatings in the Far-Infrared." Applied Opt., vol.23, pp. 2311-2326, 1984.
5. Blue, M.D. and Perkowitz, S.: "Space Exposure Effects on Optical-Baffle Coatings at Far-Infrared Wavelengths," Applied Opt., vol. 31, pp. 4305-4309, July 1992.

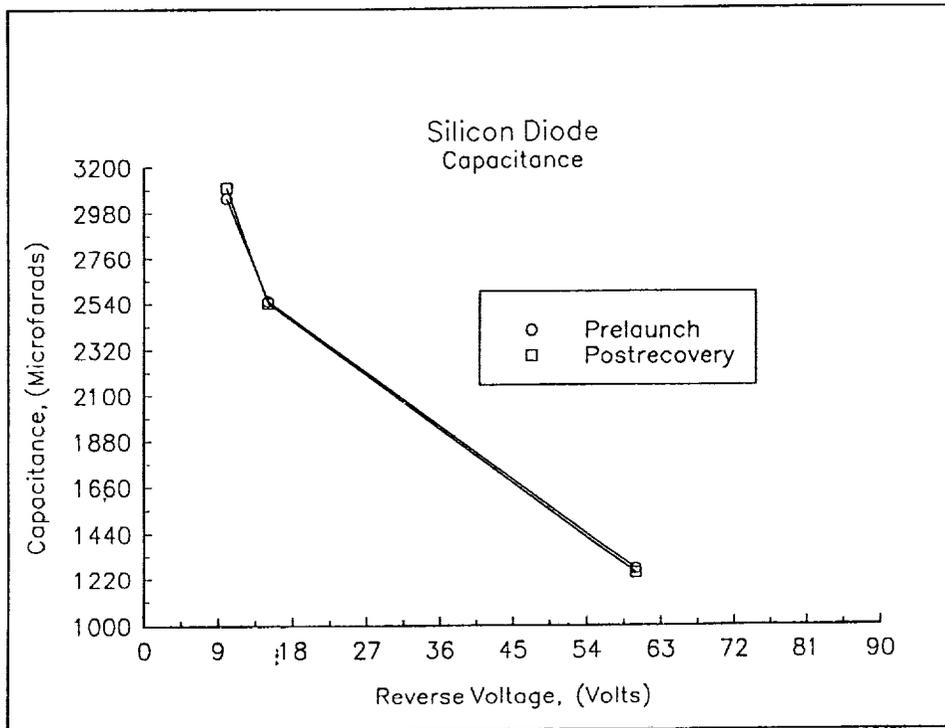


FIGURE 1. Junction capacitance versus reverse voltage for a silicon photodiode exposed to the space environment. There was no change in junction capacitance in any silicon device over the twelve years between measurements.

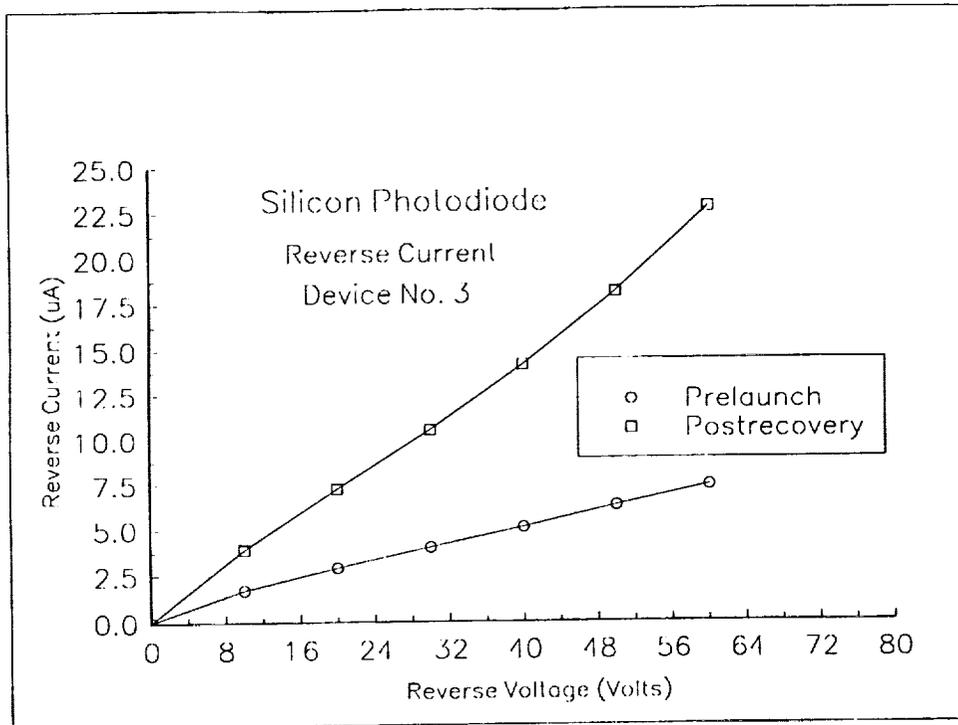


FIGURE 2. Junction current versus reverse voltage for a silicon photodiode exposed to the space environment. This diode had a scar from a micrometeorite impact. No change in diode leakage current occurred.

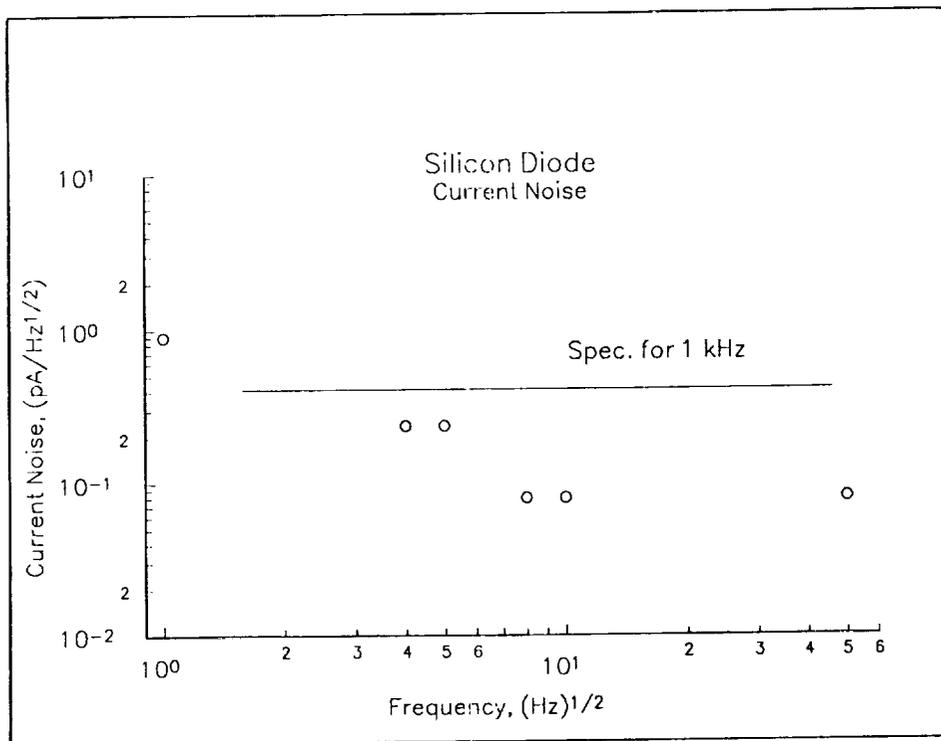


FIGURE 3. Current noise spectral density for a silicon photodiode diode. The current noise remains well within the manufacturers specification. At low frequencies, 1/f noise appears at a low level.

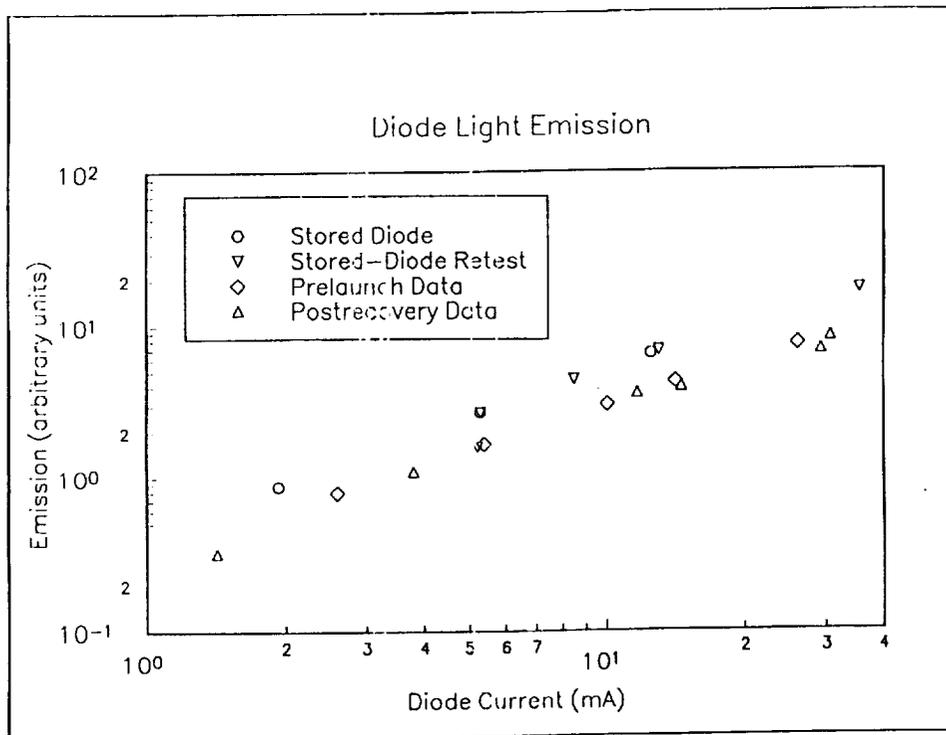


FIGURE 4. Diode emission versus current for a pair of GaAsP light-emitting diodes. Heating and hysteresis effects are characteristic of these devices. Nonetheless, the original characteristics are well reproduced.

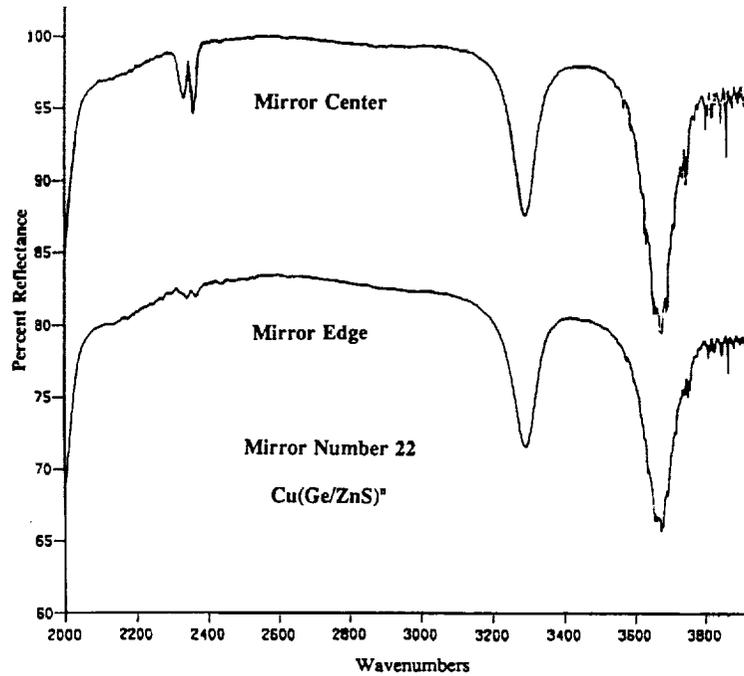


FIGURE 5. Spectral reflectance of a multilayer-dielectric mirror optimized for high reflectivity at $3.8 \mu\text{m}$ (3571 wavenumbers) after recovery. Attachment hardware covered the edges of the mirrors, often providing different reflectance spectra from the mirror center.

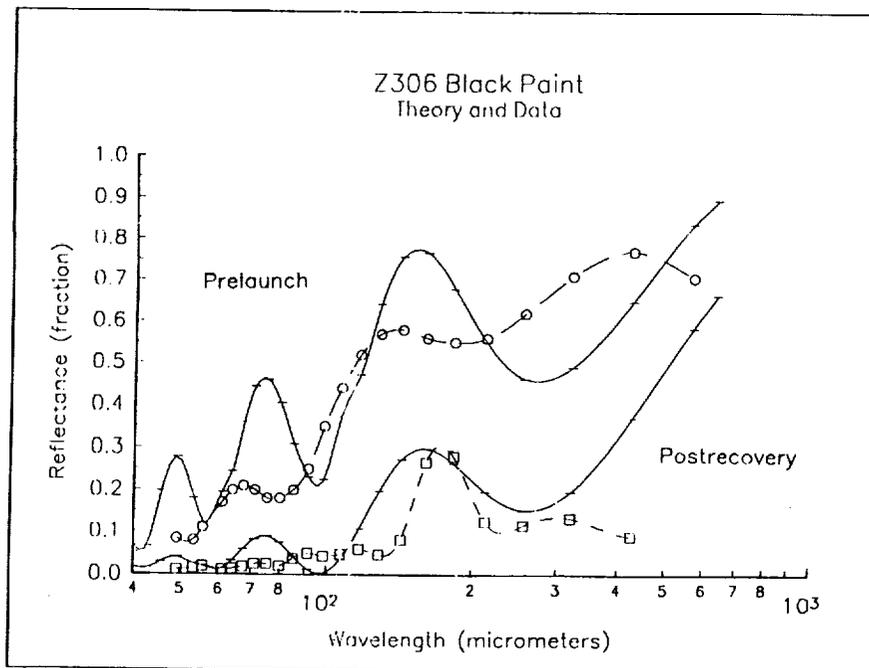


FIGURE 6. Spectral reflectance at normal incidence for Z306 black paint at extreme infrared wavelengths. Circles represent measured data. The two calculated curves represent the theory of Smith⁴ using two different values for the imaginary component of the index of refraction. The change in properties is caused by a change in absorption, not by a change in scattering.